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By

Class GNE-75M

12 March 1975

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THEFT AND DIVERSION OF SPECIAL NUCLEAR MATERIALS AND MILITARY NUCLEAR WEAPONS

Submitted for
NE 7.90
Nuclear Systems Design Study

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Preface

The class experienced a certain trepidation when we received a memo from Dr. Charles J. Bridgman, dated 3 Dec 74, advising us to pick up our text for this course (Ref 71) before the Christmas break and read it before 6 Jan 75. The study he proposed was entitled "The Design of a Protective System for Military Nuclear Devices Against Theft and Diversion." The approach suggested was to be the probabilistic method as used in the famous Rasmussen report (WASH-1400, Ref 57), which had just been released. Ostensibly, the subject appeared interesting and straightforward, since none of us really thought that military devices could possibly be stolen or diverted for "unauthorized use" by some fanatical terrorist group.

But the hooker was the subtle requirement to peruse the entire present system in order to identify weakness; the object was to assess the military safeguards against the overall system so that a cost/benefit analysis could be put in perspective. While Dr. Bridgman accurately foresaw that "...Most certainly the students will not succeed in quantifying all the probabilities involved in the time available...", little did he realize just how much would not be quantified.

Only after some eight weeks of unmerciful in-fighting and severe mental anguish did we hear (in person) Mr. Saul Levine, one of the principal experts employed on the Rasmussen report, remark that "I don't see how you can possibly come up with those probabilities." Not only that, but one of the co-authors of our text, Mr. Ted Taylor, was recorded as admitting that "the risks cannot be quantified...."

Yet the reader will easily perceive that we <u>did</u> succeed in "quantifying the probabilities." We hope that our efforts were a contribution in the right direction, and that the areas we investigated will be scruntinized

under more favorable conditions in the future. Time constraints, lack of needed data, and the generally imprecise nature of data that were available all added to the continuous aura of frustration, and this report is somewhat shallow in many areas because of those factors. Still, we feel inspired to extend our appreciation to certain individuals and groups that were particularly helpful with our problem.

We are, of course, especially thankful to Dr. Bridgman for his guidance, patience, and understanding as we undertook this study. Without his unending supervision the results reported here would never have been obtained.

We would also like to thank Mr. C. D. Tabor and his staff of the Goodyear Atomic Corporation's gaseous diffusion plant, who permitted a portion of this group to visit the plant. During this visit Mr. Tabor and his group spent several hours answering our questions pertaining to the gaseous diffusion process and the transportation of strategic materials. Their expertise aided tremendously in this study.

The personnel of the 17th Bombardment Wing, Strategic Air Command, located here at Wright-Patterson AFB, Ohio, are due special thanks for enduring our persistent ignorance; Lt Col D. F. Berthold, Chief of the SAC Command Post, and Captain C. Schmidt, 17th Security Police Squadron Commander, were particularly helpful.

We are also grateful to Maj Braxton, Nuclear Munitions Branch of the Directorate of Materiel Management, at Headquarters Air Force Logistics Command, Wright-Patterson AFB.

The Air Force Weapons Laboratory, in particular Lt Col Jimmy Richardson of the Nuclear Safety Division, is due special acknowledgment for their interest in the project, and for their financial aid in supporting the visit of instructors from the Interservice Nuclear Weapons School, Kirt-

land AFB, New Mexico. The knowledge gained from the briefings presented to us were singularly helpful in getting us started.

Finally, the class wishes to thank our wives for their continued patience and understanding throughout this rather difficult project.

Class GNE-75M
12 March 1975

Foreward by the Instructor

At about the time we undertook this class study (late autumn 1974), Mr. Theodore B. Taylor, the co-author of "Nuclear Theft: Risks and Safeguards", (Ref 71) spoke before a group of Sandia Corporation employees and Air Force officers from Kirtland AFB at Sandia Laboratories, Albuquerque NM. One of the audience taped Mr. Taylor's words and he was good enough to share the tape with the class. Mr. Taylor, at one point said:

> "There is another reason why I think this has to be, - to some level of detail - discussed openly, publically. That is that the risks that are involved... can't be described quantitatively. I think it is not possible... to give a number with any useful range of accuracy, that says what is the risk that nuclear explosives will be used for highly destructive purposes"

Yet a quantitative evaluation of that risk is exactly what this study attempts to make. The key relationships are the use of airline hijacking data (Fig 2) for the initiating probability and the probability of being caught as a function of time after a "henious crime", Figure 3.

It is my belief that both of these are "interesting" propositions. While I would be very cautions in using the risk numbers generated here for any serious purpose, I do think the method proposed here may have some merit for further study.

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Abstract

Theft and diversion of nuclear materials suitable for construction of nuclear explosives or dispersal weapons has received considerable recent attention in the public domain. A design study was undertaken to improve the security systems for nuclear materials and weaponry. In addition to an anlysis of the threat, calculations are presented to quantify the amount of material necessary to produce a significant nuclear yield, as well as models to deduce a probability of diversion and hazards associated with plutonium dispersion. These methods were closely patterned after a similar analysis contained in the recently released Reactor Safety Study (WASH 1400). Several event trees were considered with different initiating events representing theft or diversion at different stages of nuclear materials processing or utilization. Unlike the Reactor Safety Report, fault trees were of limited use in assigning probabilities--especially for the initiating event itself. Instead, probabilities were estimated based on models which were constructed from available data on similar terrorist activities such as airline hijackings, mass murders, and other equivalent antisocial acts. These techniques had only limited success and predicted only a gross upper bound for final probabilities. Relative risk levels are shown to be approximately an order of magnitude less than the risk posed by most common accidents.

I. Introduction

Background

A dominant question in American Society today is this country's ability to protect its stockpile of nuclear weapons and nuclear weapons material against theft and diversion by terrorist groups. Several factors exist today which make this threat an important and credible issue. The professional skills, intelligence networks, finances, and armaments of terrorist groups have increased throughout the world. International terrorist groups presently exist which have the ability to infiltrate highly trained teams of men into this country without detection. It has also been shown that these groups have the ability to operate in urban areas with near impunity for long periords of time.

In addition to the increase in the ability of terrorists to acquire such material, the dissemination of information regarding conversion of nuclear materials to weapons has also increased. While such information may have always been available in unclassified literature it was masked by a great deal of irrelevant and incorrect information. Unclassified documents exist today, however, which accurately and precisely define these processes. A final factor contributing to the importance of the terrorist threat today is the increase in the availability of knowledgeable personnel. There is a slow but continual movement of these personnel into and out of the areas of weapons design and manufacturing. These moves are sometimes forced and can therefore instill strong resentments in the people involved. As a result, larger and larger numbers of people with experience in processing special nuclear materials and with varying psychological attitudes are being dispersed in the overall industrial community.

It can therefore be concluded that terrorist groups are likely to have available to them the sort of technical knowledge needed to use the now widely disseminated instructions for processing fissile materials and building a nuclear weapon. Because of the factors previously mentioned we must conclude that the probability of these groups acquiring such materials is on the increase. The terrorist threat is therefore a credible one and its impact on society must be precisely and closely investigated.

Purpose

Therefore the goal of this study was to analyze the present safeguards system for the protection of military nuclear devices against theft and diversion by such terrorists and identify areas for increased protection. This goal was approached via three specific objectives. The first objective was to analyze the life cycle, from mine through deployment through retirement, of military nuclear devices. The purpose of this analysis was to identify weaknesses in the present safeguards system. However, rather than identifying weaknesses through a scenario approach, the probablistic methods of event tree analysis such as recently used in the Rasmussen report on light water reactors, REF 57 were used.

The second specific objective of this study was to quantify the risk associated with military nuclear devices. Here the general pattern of the Rasmussen report was followed. That is probabilities were computed for each branch on the event tree and then these probabilities were multiplied by the consequences of each branch (nuclear explosion, partial explosion or dispersal) to find the probability of causing a number of fatalities. However this study departs from the Rasmussen study in the

computation of probabilities within the event tree. The Rasmussen report made extensive use of fault tree analysis. Fault tree analysis is applicable to mechanical failures but is of limited use in predicting deliberate human actions such as sabotage. An alternate approach to predicting probabilities of human actions is developed here and is explained in the next chapter, Methodology. The individual event trees are developed in chapters III, IV & V. An integral part of this second objective was to compare the risk (in lethalities per person per year) associated with diversion of nuclear material with the risk associated with both natural and man-made hazards.

Finally the third specific objective was to determine which specific points of the nuclear life cycle needed more security in order to reduce the total risk associated with nuclear devices. The use of event tree analysis allows a pinpointing of the most cost-effective areas to apply security dollars. That is the greatest reduction in risk at the lowest cost to the public. This third objective is addressed in Chapter VI.

II. Methodology

The basic plan of attack used in this study was essentially the same as that used in WASH-1400 (Ref 57). A four step sequence, shown in simplified flow chart form in Figure 1, evolved to arrive at the principal goal: risk assessment.

The first step or initiating event proved to be a formidable obstacle since there is no evidence of a diversion attempt having occurred in the United States since the advent of nuclear weapons. The usual way of estimating risks for frequent (high probability) events is to use data from the historical record of such events covering a suitably wide variety of states of prior information. Information from such studies can then be used as a basis for estimating the risk expected in some future time. However, where potential risks occur at such a low frequency that they have never been observed, such risks are extremely difficult to estimate and express in a meaningful way in comparison to those of more frequent events. Bayesian inference techniques can be applied to these situations so that an estimate of an event's occurrence can be achieved, even though the event may never have been observed. But a "prior distribution" of some sort is required, or at least some conjugate family of distributions, which includes distributions with different location, dispersion, shape, etc., to represent the variety of states of prior information mentioned previously. The prior distribution used here is the distribution of airline hi-jackings per year. How this distribution is fit to diversion of nuclear materials, is explained in the next section of this chapter.

The second step consists of breaking up a rare event into a series of more likely events for which individual probabilities of occurrence

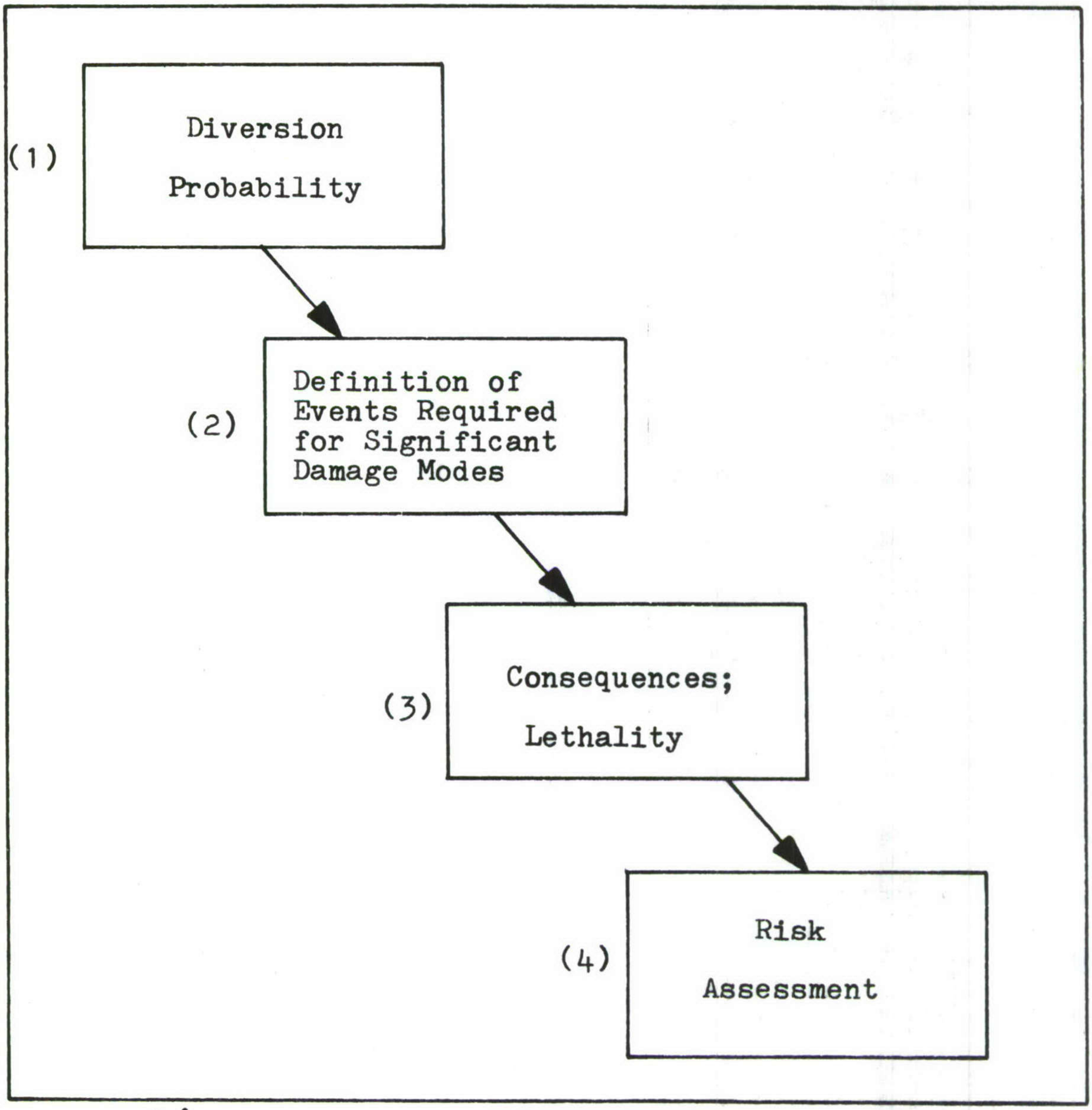

Figure 1: Four Steps in Determining Risk.

are known (in a conjugate sense) or can be computed. The method of computation is explained in the last section of this chapter. The breaking up of rare events into a series of more likely events is the basic principle of the event tree technique used in WASH-1400. But where fault tree methodology was often used ~~as an aid~~ in WASH-1400, it was of little use here. Rather, the absence of existing data relative to success and failure posed several perplexing questions. Human errors and human abilities obviously play an important role in this regard. It became necessary to formulate additional computational models further explained below, in order to compute individual probabilities for steps in the event trees.

The third step required a model to calculate the consequences of various possible damage modes, including health hazards due to dispersion of plutonium as well as the direct effects of a nuclear explosion.

The final step was simply the multiplication of the final probabilities from each branch of the event trees times the consequences to obtain lethalities. When these lethalities are divided by the exposed population we have a risk assessment in terms of lethality/person-year. This in turn permits comparison with some previously established statistical data. This comparison is discussed in Section VI and forms the framework for evaluating risk versus consequence.

<u>Calculation of the Initiating Event or Diversion Probability</u>

Since no diversions of significant amounts of nuclear material are known to have occurred in the United States one is forced into using historical data for other crimes to estimate the probability of theft of nuclear material. The choice made here was to employ the data on airplane hi-jackings. This was motivated by two factors:

1. The extremely violent threat to individuals and institutions posed by airplane hi-jackings is similar to the threat presented by a group threatening to explode a homemade nuclear bomb.

2. The data is readily available and usuable with only small modifications.

The data pertaining to aircraft hi-jackings was for aircraft flying within the United States of America. There were two reasons for limiting the data to this criteria. First, the assumed threat of this study was a terrorist group within the United States. And secondly, the aircraft within the United States were operating under one set of laws. Thus, the data that was chosen would have been the result of someone within the U. S. hi-jacking an airplane under federal law.

Although only one source of data was finally selected, other sources were checked for verifying the data. The percent of successful hi-jackings was computed simply by dividing the number of successful hi-jackings by the total number of attempts. The data accepted for use within this study is given in the table below.

Hi-jackings, U. S.	1965	1968	1969	1970	1971	1972
Total Attempts	4	22	40	27	27	30
Number Successful	1	18	33	18	12	10
% Successful	25.0	81.8	82.5	66.7	44.4	32.3

Table I. U. S. Airplane Hi-jackings (Ref 65:577)

The number of successful hi-jackings per year is plotted in Figure 2. The cumulative probability or total number of successful hi-jackings since 1965 is 92, and of course is equal to the area under the curve. Obviously this data can not be taken over directly to diversion of nuclear material since there has never been a successful diversion. That is the

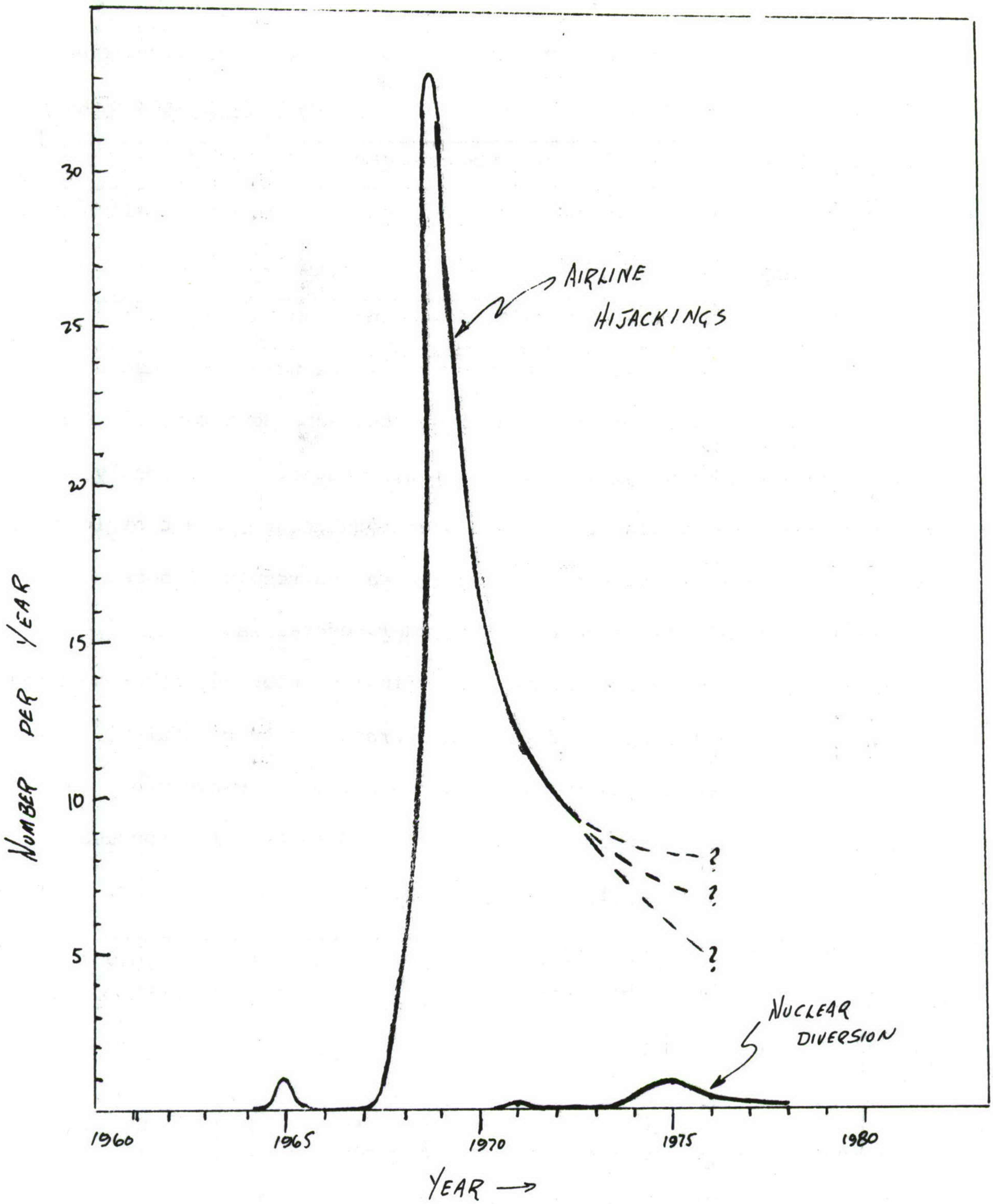

Figure 2: Probability per year of Airplane Hijackings (experimental) & Probability per year of Nuclear Diversion (computed).

cumulative probability or area under a probability per year of nuclear diversion curve must be less than one. We make the highly conservative assumption that there will be a diversion tomorrow so that the area under the nuclear diversion curve is exactly one. (Conservative in the sense that this assumption will predict limiting probabilities on the large side.) Thus we have a probability-per-year curve for nuclear diversion with a shape determined by airline hi-jackings per year and an area or cumulative probability of one. However, there is no reason to believe that the maximum in the nuclear curve will lie under the maximum in the airline curve. It may be shifted by a few or several years to the left or right. We assume that the approximate time of increased security is the point of correspondence. Specifically, increased security on the airlines commenced in mid 1968, and it can be seen from Table I. that the probability of success for hi-jackers reached a maximum at that point in time and then began a decline. In terms of the calculus represented by Figure 2, the second derivative or "acceleration" of the probability curve experienced an inflection in 1968 which resulted in a maximum in the function in 1969 and then a subsequent decline. We assume that increased security for nuclear diversion occurred in 1974, so that the curve for nuclear diversion is shifted six years to the future or to the right in Figure 2. Now it is necessary to normalize the area under the nuclear diversion curve. As before we assume that a diversion occurs tomorrow and further that is the only diversion during 1975, so that the cumulative probability under the nuclear curve is one through the end of 1975. Since 1975 with respect to nuclear diversion corresponds to 1969 with respect to airline hi-jackings, the normalization factor is 1/52. (There are a total of

52 airline hi-jackings through the end of 1969). This results in the yearly probability of nuclear diversion as shown in Figure 2 and in Table II below.

	1971	1972	1973	1974	1975	1976	1977	1978
Probability per year of Nuclear Diversion	0.019	0	0	0.346	0.635	0.346	0.231	0.192

Table II. Computed Probability per year for Nuclear Diversion

The computed probabilities in Table II, while large, do not equate to successful use of those nuclear materials by terrorists, they simply predict in conservatively large way, the initiating event, that is, the probability of the diversion itself. Successful nuclear explosion or dispersion depends on success in a sequence of events which will be analyzed in the event trees of the next chapter. First, however, it shall be necessary to develop a method of computing probabilities for the individual events in those event trees.

Human Ability Model

Since the majority of events in the individual event trees were not mechanical events, it became obvious that standard fault tree analysis could not be used to establish the probability of success of many events. In order to establish these probabilities, the human ability model was constructed.

The basic assumption of this model is that a group of terrorists can do anything that has been done provided they have unlimited time in which to do it. For example, this model assumes a small group can reduce a fairly large amount (several hundred kilograms) of enriched UF_6 to uranium metal provided they are not apprenended before the task is completed.

Therefore, instead of quantifying human abilities, it becomes necessary to quantify the amount of time that a terrorist group has at its disposal before being apprehended for the diversion of nuclear material. A second assumption then, of this model, is that any diversion of critical-mass sizes of nuclear material, will be detected within one day of its occurrence.

Ideally, the amount of time after a diversion available to a terrorist organization would be determined by years of statistics that could be graphically presented as "the number of criminals apprehended" versus "the time elapsed since the crime was committed". A graph of this type could easily be transformed into a "probability of being apprehended" as a function of time. Then, the probability of success of a human-ability event (P_s(h-a)), is just one minus the probability that the group will be apprehended ($P_a(t)$) in the time it takes to perform the particular action.

For example, if it is estimated that a small group could reduce 200 kg of UF_6 to uranium metal in 14 days, then the probability of success is given by:

$$P_s \text{ } (UF_6 \text{ reduction}) = 1 - P_a \text{ } (14)$$

where $P_a(14)$ would be determined from the graph described above.

Unfortunately, the years of statistics necessary to construct an accurate $P_a(t)$ function were not available. A less accurate function was constructed by scanning the past five years of "Facts on File" (Ref 65) to obtain 30 heineous crimes (murders, kidnappings, large robberies, bombings) such that the criminals were eventually apprehended. The crimes were chosen generally because the FBI was involved in the law enforcement activities. This data was manually converted to a cumulative probability distribution function, $P_a(t)$. The biasing, introduced

by using only crimes where the criminals were eventually caught, was then removed by multiplying the original $P_a(t)$ by the ratio of solved murders to total murders (0.817) (Ref 65). The final $P_a(t)$ that was used to assign probabilities to human-ability events is shown in Figure 3. The details of its calculation are found in Appendix F.

Summary

In this chapter we have presented the methodology for predicting the initial act of diversion and a method for predicting the probability of success for the subsequent necessary acts in the detonation or dispersal of the nuclear material. These methods will be employed in the event trees of the next three chapters, in which diversion of uranium is examined (chapter III), diversion of plutonium is examined (chapter IV) and theft of a nuclear weapon from the military is considered. In each case one or more initiating events are considered, event trees are defined and probabilities assigned so as to arrive at a final probability of explosion or detonation. Finally the consequences of that event are evaluated so as to arrive at a general population risk assessment in lethalities per year.

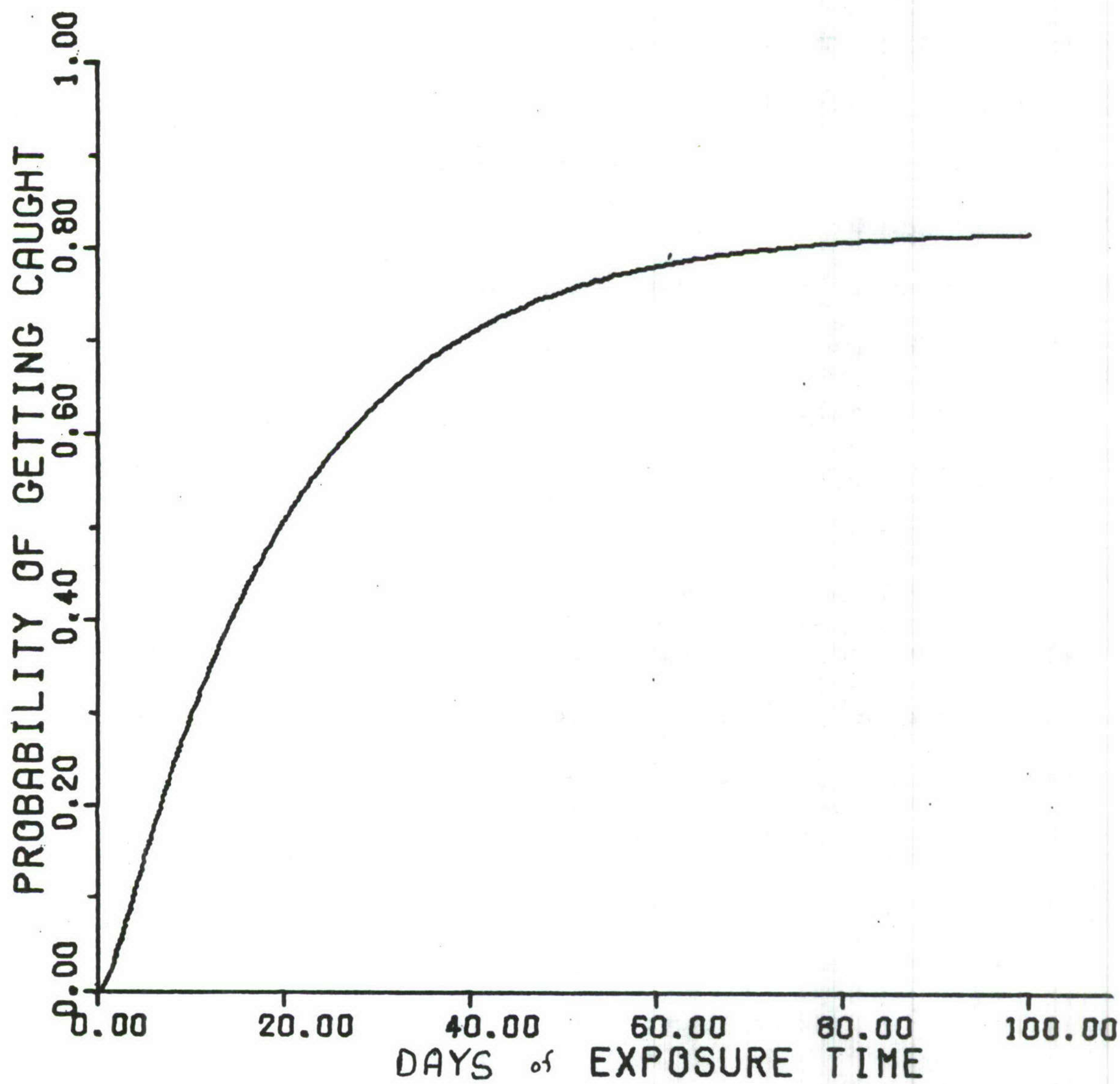

Figure 3: Probability of Being Caught as a Function of Time after Crime for 30 heineous Crimes (murders, kidnapings, large robberies, bombings, etc.)

III. THEFT OF URANIUM

The entire uranium cycle (see Figure 4) from the mine to a weapon was examined. Two broad possibilities for diversion exist. Enriched uranium (at least 37.5% U235) might be stolen and used to make an explosive device or unenriched uranium might be stolen, enriched by the terrorists and then used to make an explosive device. The process of enrichment by various methods is considered in Appendix A. The methods considered in Appendix A include; gaseous diffusion, centrifuge, laser separation, jet diffusion, electrostatic and magnetic. In each case it was concluded that the facilities required and/or the time required were so vast as to make clandestine enrichment highly improbable. This leaves only the enriched phases of the uranium production cycle as viable targets.

Criticality Calculations

Rough calculations (one fast group, diffusion) were made to determine the amount of uranium in the metallic, oxide and fluoride states that would be needed to produce an exactly bare critical mass of the material. Two concentrations of U^{235} compound and pure metal were considered - 37.5% and 93.5%. These are the most likely concentrations to be found in transit between, and in use in, most material processing plants. (U^{235} enrichment to 97.65% is possible, however, 93.5% was used as the most likely enrichment. The difference in the calculations would be almost negligible.) The amounts of the different materials needed to construct one critical mass are listed in Table III below. The calculations are carried out in Appendix B.

The masses contained in Table III are those necessary for an exactly critical mass. An explosive device requires masses in excess

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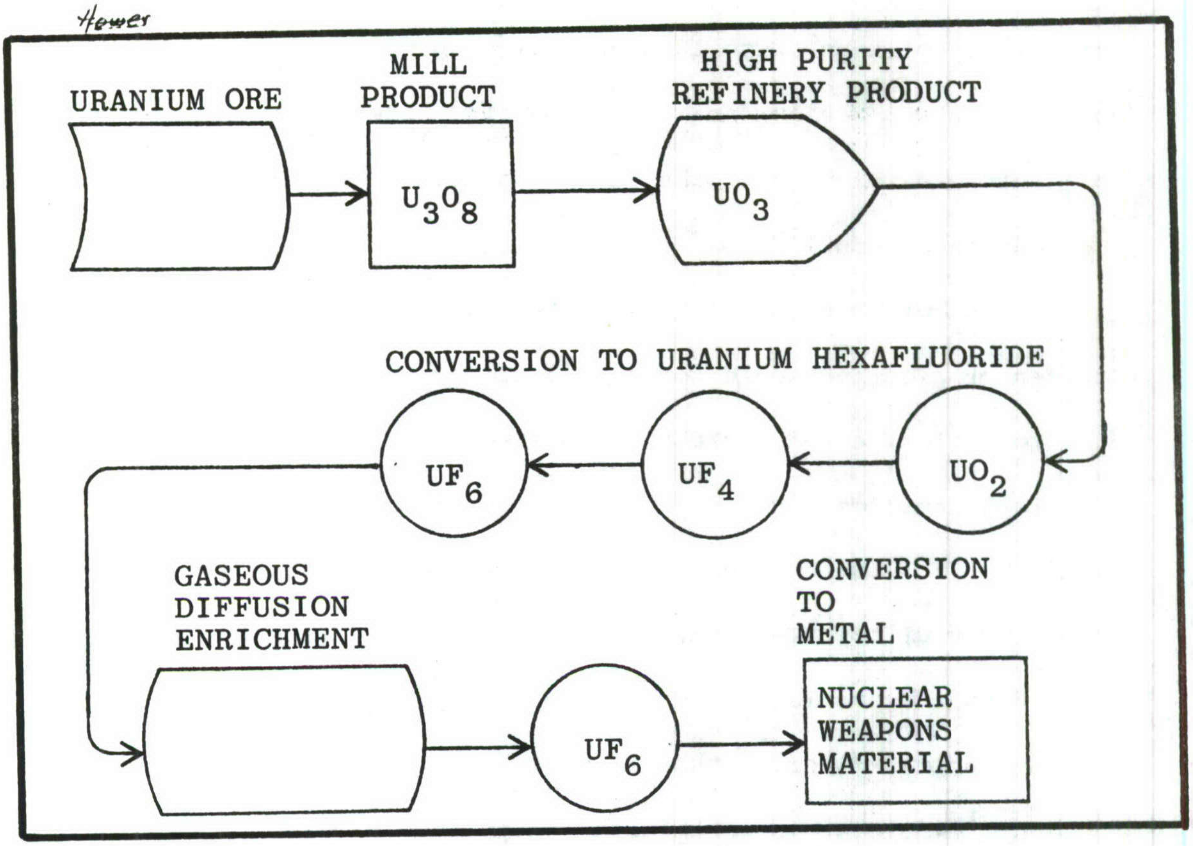


Figure 4. Uranium Fuel Cycle.

Material	MASS(kg)		WEIGHT(lbs)	
	37.5%	93.5%	37.5%	93.5%
U^{235}	252.7	59.3	555.9	130
UO_2	347.8	136.8	764.7	301
UF_6	2531	545.6	5568	1200
		100%		100%
U^{235}		55.1		121.2

Table III. Amount of U^{235} Compounds for One Critical Mass

of this by perhaps 50 to 100% depending upon the value of the multiplication factor (See Appendix A). Therefore the use of 37.5% uranium in any form was ruled out. The weights are just too large to be utilized. Further the compounds UO_2 & UF_6 of 93.5% enriched uranium were also ruled out both because of their weight and because the presence of oxygen or fluorine would serve as a slight moderating agent, increasing neutron lifetime and thereby decreasing the potential yields to near fizzle quantities. However we shall continue to consider the theft of 93.5% UF_6 as viable threat coupled with subsequent reduction of the 93.5% uranium to pure metal.

From the previous discussion of enrichment processes, the diversion, of any nuclear material that is enriched to less than 93.5% in the isotope U^{235} would prove worthless (except from a monetary standpoint) to a terrorist organization intent on constructing a crude nuclear device. This assumption eliminates a majority of the refinement cycles and Nuclear Regulatory Commission (NRC) controlled site locations as a probable target for an attempted nuclear diversion. For NRC controlled sites, this restriction reduces the number of probable terrorist targets to two; (1) Goodyear Atomic Corporation which is located near Portsmouth, Ohio and; (2) Oak Ridge National Laboratory at Oak Ridge, Tennessee. Considered as also being possible targets are shipments of highly enriched UF_6 (97 percent in the isotope U^{235}) from Portsmouth to Oak Ridge and shipments of weapons grade U^{235} metal from Oak Ridge to Pantex Corporation in Amarillo, Texas.

An attempted diversion, here after referred to as an initiating event for purposes of event tree analysis, has now been limited to four targets, two of which are fixed sites and the other two being in

transit shipments of nuclear materials. Since no distinction in ease of diversion from on site locations and from shipments in transit could be found, the total number of initiating events was reduced even further to two, diversion of 43.5% metal or diversion of 93.5% UF_6. Thus all event tree analyses presented in the next section start with, as an initiating event, either diversion of highly enriched UF_6 or diversion of U^{235} metal.

Initiating Events

The first initiating event considered is the diversion of highly enriched UF_6 at an enrichment facility or enroute from such a facility. The event tree for this initiating event consists of four subsequent events which lead to the detonation of a nuclear device by a terrorist organization... These are: (1) converting the UF_6 (enriched to 97% in the isotope U^{235}) to uranium metal; (2) the actual putting together or assembly of a "gun type" nuclear device (incorporated in this event are the machining of subcritical masses, constructing or procuring a casing for the subcritical masses, and installing the high explosives.); (3) placing the weapon in an area that would lead to a maximum number of lethalities without the weapon predetonating; and (4) the weapon, after being assembled and placed, actually detonating as planned. These four events, following the initiating event of an actual diversion of UF_6, would lead to a nuclear detonation.

Individual Events. A closer look into the individual events is required to clarify the probabilities which are assigned to each of them. These are the probabilities which ultimately lead to the probability of a nuclear detonation, given an initiating event. They are:

(1) Diversion of enough highly enriched UF_6 while at Portsmouth, Ohio or while in transit to Oak Ridge, Tennessee to construct a critical

mass. The probability of this event (for 1975) was obtained from airline hi-jacking data as described in Chapter II, "Diversion Probability Model."

(2) Conversion of the highly enriched UF_6 to U^{235} metal required for weapon assembly. Since it is impossible to determine whether a terrorist group will have among its members a qualified chemist who would know how to convert UF_6 to U^{235} metal, assigning a probability to this event based on fault tree analysis was not feasible. To find this probability we had to reply on the "Human Ability Model" (Chapter II) where the probability of a terrorist group being able to perform a task was assumed to be one (P=1) unless they were apprehended prior to completing the task. If they were apprehended prior to completing the task the probability assigned to the event would be zero. (P=0). In talking with several qualified radiochemists at AFIT and the Air Force Materials Lab (AFML) it was estimated that it would require between 4 days and 39 days with a most probable time of 14 days to convert 157 kg of UF_6 to 105 kg of U^{235} metal. To obtain 78 kg of U^{235} metal from 117 kg of highly enriched UF_6 it would require between 3 days and 29 days with a most probable time of 10 days.

(3) Assembling the Weapon. Here again we run into the necessity utilizing the "Human Ability Model" to assign a probability rather than through a fault tree analysis. We have to assume a terrorist group <u>can</u> assemble the weapon given enough time and they are not apprehended prior to completing the construction. The probability of successfully completing the event will decrease the longer it takes to complete the task, i.e. the probability of success will decrease as their exposure time increases. After conversations with members of the AFIT machine

shop it was estimated that, regardless of whether they were working with 78 kg or 105 kg of U^{235} metal, the time required to assemble the "gun type" device would be between 2 days and 20 days with a most probable time of 11 days. Since the people who figured out this time frame for assembly had never worked with U^{235} metal, these estimates were based on working with similar quantities of lead (Pb).

Events (2) and (3) which both relied on the "Human Ability Model" for probability assignment, though separate events, may be grouped into one event and assigned a single probability based on the total time required (exposure time) to convert the UF_6 to U^{235} metal and assemble the weapon. These total times along with the corresponding probabilities of success are given in Table IV for two critical mass sizes of 78 kg and 105 kg of U^{235}.

Critical Mass	Time Req'd (days) to convert UF_6		Time Req'd (days) to Assemble Weapon	Total Time (t) days	Probability of Success *
78 kg of U^{235}	Min	3	2	5	.70
	Most Prob	10	11	21	.40
	Max	29	20	49	.31
105 kg of U^{235}	Min	4	2	6	.67
	Most Prob	14	11	25	.37
	Min	39	20	59	.28

Table IV. Probability of Success for Making a Nuclear Weapon from UF^6.
*from Figure 3.

The probabilities which appear on the event tree (Fig 5) were those obtained directly from Figure 3, Chapter 2 by assuming a most probable time to convert and assemble a weapon containing 105 kg of U^{235}.

(4) Weapon placement without predetonation: Statistics from FBI files concerning "home-made" bombs (Ref 69) being placed without predetonation were available and, from these statistics, the probability of success for this event was determined to be P = 0.818.

(5) Weapon detonation. This probability was also based on extensive FBI data concerning the number of "home-made" bombs that were successfully placed in a pre-determined position but failed to explode as planned. The probability assigned to this event was P = 0.749 (Ref 68).

Multiplication of the probabilities assigned to events (1) - (5) leads to the probability that given an attempted diversion of 97% U^{235} UF_6, a terrorist organization will be able to successfully detonate a "home-made" nuclear device (Fig 5).

The consequences of such a device being detonated will be dependent on two main factors: (1) the population density in the vicinity of the detonation and; (2) the yield of the detonation. In determining consequences in terms of lethalities per person-year, a population density of 7000 persons/sq mi was assumed if the weapon was successfully placed, and a population density of 1000 persons/sq mi if the weapon predetonated. The number of lethalities will of course increase with increasing weapon yield. Lethality calculations are carried out in Appendix C.

Risk assessment, in lethalities/person-year, initiated by an attempted diversion of UF_6 are given in Table V. Fatalities per person year were computed by multiplying the probability of the event per year times the fatalities as given in Table C-5 and dividing by a estimated U. S. population of 213,000,000. Tabulated are risks determined for two yields (1 Kt and 5 Kt) and whether or not the device predetonated.

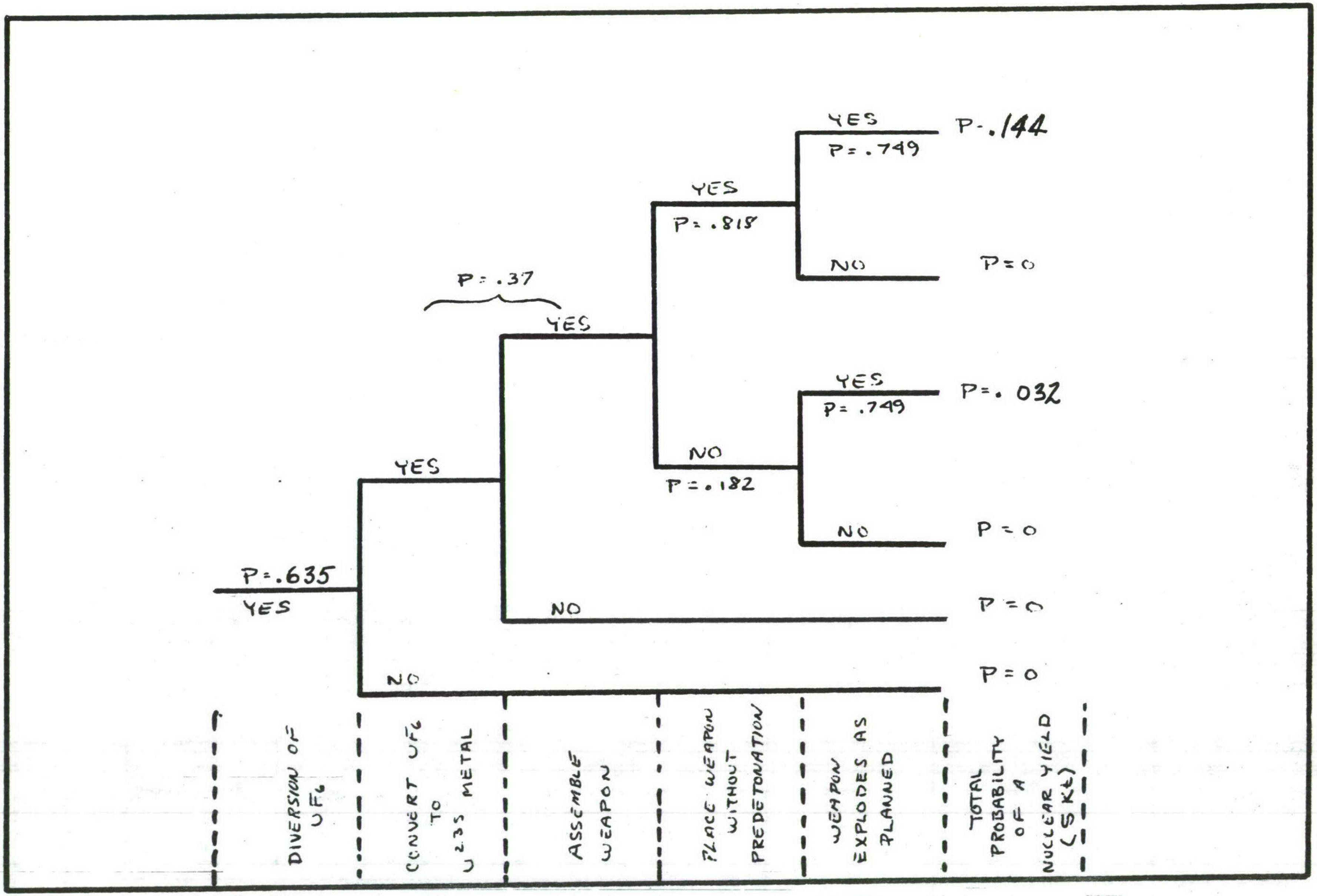


FIGURE 5: EVENT TREE FOR ATTEMPTED DIVERSION OF UF_6

YIELD	EXPOSURE TIME	DIVERSION	CONVERT UF_6 AND ASSEMBLE WEAPON	WEAPON PLACEMENT	EXPLODING AS PLANNED	TOTAL PROBABILITY OF A NUCLEAR YIELD	LETHALITIES / PERSON - YR
		IF ALL EVENTS SUCCESSFUL					
		PROBABILITY OF					
1 Kt	MINIMUM	.635	.70	.818	.749	.272	2.03×10^{-6}
	MOST PROBABLE	.635	.40	.818	.749	.156	1.17×10^{-6}
	MAXIMUM	.635	.31	.818	.749	.121	9.02×10^{-7}
5 Kt	MINIMUM	.635	.67	.818	.749	.261	4.78×10^{-6}
	MOST PROBABLE	.635	.37	.818	.749	.144	2.64×10^{-6}
	MAXIMUM	.635	.31	.818	.749	.121	2.22×10^{-6}
		IF WEAPON PREDETONATION					
1 Kt	MINIMUM	.635	.70	.182	.749	.0606	6.45×10^{-8}
	MOST PROBABLE	.635	.40	.182	.749	.0346	3.68×10^{-8}
	MAXIMUM	.635	.31	.182	.749	.0268	2.85×10^{-8}
5 Kt	MINIMUM	.635	.67	.182	.749	.0580	1.52×10^{-7}
	MOST PROBABLE	.635	.37	.182	.749	.0320	8.37×10^{-8}
	MAXIMUM	.635	.31	.182	.749	.0268	7.01×10^{-8}

TABLE V : RISK ASSESSMENTS FOR ATTEMPTED DIVERSION OF UF_6

In the latter case Table C-5 values were again used but divided by 7 which assumes that the population is 1000/sq mile but that the ratio of persons outside to inside brick or reinforce buildings is the same as assumed in Appendix C for urban areas. Also considered are differences in risk due to variations in exposure time required to complete events (2) and (3).

The second initiating event that was considered was the diversion U^{235} metal enriched to 97% in the isotope U^{235}. The event tree for this initiating event is identical to that used for diversion of UF_6 except that event (2), conversion of UF_6 to U^{235} metal, is not necessary. Probabilities for diversion, weapon placement without predetonation, and weapon detonation as planned will all be the same. The only difference between the two trees will be the probability of successfully assembling a weapon. This is due to the fact that since conversion of UF_6 is not required, the exposure times will be greatly diminished and hence the probability of successful assembly will be increased.

As previously stated, time estimates for assembling a nuclear device would be the same for a yield of 1 kiloton (78 kg of U^{235}) and for a yield of 5 kilotons (105 kg of U^{235}). These exposure times, along with the corresponding probabilities of success based on these times, are given in Table VI. The probability of success for the most probable exposure time is depicted in the event tree (Fig 6). In determining lethalities/person-yr for an attempted diversion of U^{235} metal, the same assumptions concerning lethality dependence on yield and weapon predetonation were considered.

Risk assessment, in lethalities/person-yr, initiated by an attempted diversion of U^{235} metal are given in Table VII for yields

of 1 kiloton and 5 kiloton. Varying risk depending on exposure time and weapon predetonation are also tabulated.

Critical Mass	Times Req'd (day) to Assemble Weapon		Probability of Success *
78 kg or 105 kg of U^{235}	Min.	2	.78
	Most Prob.	11	.54
	Max.	20	.41

Table VI. Probability of Success for Making a Nuclear Weapon from U^{235} Metal.

* from Figure 3.

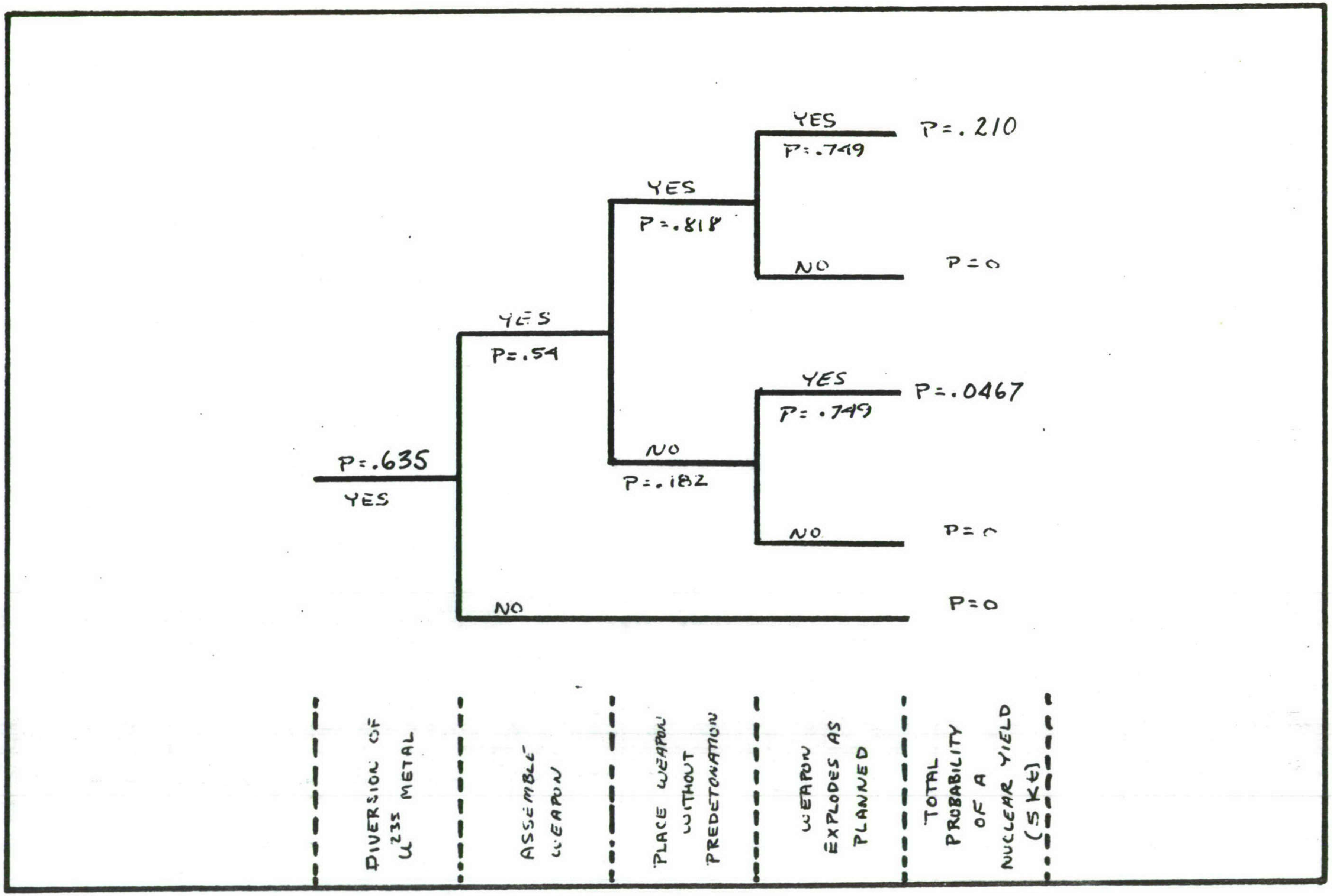


FIGURE 6. EVENT TREE FOR ATTEMPTED DIVERSION OF U^{235} METAL

YIELD	EXPOSURE TIME	IF ALL EVENTS SUCCESSFUL — PROBABILITY OF: DIVERSION	ASSEMBLE WEAPON	WEAPON PLACEMENT	EXPLODING AS PLANNED	TOTAL PROBABILITY OF A NUCLEAR YIELD	LETHALITIES / PERSON-YR
1 Kt	MINIMUM	.635	.78	.818	.749	.303	2.26×10^{-6}
	MOST PROBABLE	.635	.54	.818	.749	.210	1.56×10^{-6}
	MAXIMUM	.635	.41	.818	.749	.160	1.19×10^{-6}
5 Kt	MINIMUM	.635	.78	.818	.749	.303	5.55×10^{-6}
	MOST PROBABLE	.635	.54	.818	.749	.210	3.85×10^{-6}
	MAXIMUM	.635	.41	.818	.749	.160	2.93×10^{-6}
		IF WEAPON PREDETONATION					
1 Kt	MINIMUM	.635	.78	.182	.749	.0675	7.18×10^{-8}
	MOST PROBABLE	.635	.54	.182	.749	.0467	4.97×10^{-8}
	MAXIMUM	.635	.41	.182	.749	.0355	3.78×10^{-8}
5 Kt	MINIMUM	.635	.78	.182	.749	.0675	1.77×10^{-7}
	MOST PROBABLE	.635	.54	.182	.749	.0467	1.22×10^{-7}
	MAXIMUM	.635	.41	.182	.749	.0355	9.29×10^{-8}

TABLE VII: RISK ASSESSMENTS FOR ATTEMPTED DIVERSION OF U^{235} METAL

IV. Theft of Plutonium

Introduction

The plutonium event tree attempts to define the events and probabilities of their occurrence from the diversion of plutonium to its ultimate antisocial use. In order to limit the extent of the event tree and prevent endless circles in the event tree the following general assumptions were made:

(1) A diversion results in 40 kilograms of plutonium, in any form, being acquired.

(2) The diversion of plutonium alloy is to be used for making a bomb.

(3) The diversion is conducted by a group.

(4) The terrorists possess the equipment necessary and have the capability to utilize the plutonium given enough time.

Since the amount of plutonium carried during transport is unknown, the assumption is made that enough plutonium is diverted to construct a reasonable device. The assumption that the diversion of plutonium alloy is for the use of a bomb is made because the plutonium is ready for use and the risk of theft is much greater than for PuO_2. Assumption 3 is made because if one person is involved, the probabilities of failure are much higher, primarily because the time periods involved are much longer. Therefore, the probabilities of capture are higher. Assumption 4 is made because the equipment involved is readily available on the open market or can be constructed and the technology involved can be found in most good technical libraries (Ref 6, 29, 30, 31, 40, 63, 70, 71).

Throughout the event tree, many of the events involved decision processes. Therefore, in order to arrive at reasonable probabilities, a

decision model had to be assumed. This model and the choices involved are explained in the next section.

Event Tree Branching Probabilities

When considering plutonium, there are several choices of how to use the plutonium. A study of political violence; as explained in Appendix G, Determining the Threat; indicates that options leading to great numbers of lethalities will be least favorable. Therefore, the probability for lethal options was assumed to be 0.3 and 0.7 for less lethal options. These probabilities apply in cases where the terrorists have a choice, such as:

(1) using the plutonium for blackmail, building a bomb, or dispersing the material.

(2) building a Pu or PuO_2 bomb.

(3) placement in populated areas vs. unpopulated areas

(4) dispersal inside a building, outside from a point, or outside in line

(5) picking weather conditions

For the first choice, blackmail was considered non-lethal and the bomb and dispersal were considered lethal. However, indications from subversive activities (Ref 32) are that dramatic events are considered most favorable. In addition, a bomb or dispersal need not be used in lethal fashion. Therefore, the decision probabilities were weighted and assumed equal, or 0.5. If the lethal option is taken, a choice must be made between building a bomb or a dispersal device. Although dispersal is a much easier option, it does not possess dramatic effect of a bomb. Conversations with Dr. Kimball (Ref 32) have indicated that the use of a dispersal device has almost no appeal. However, considering the

potential lethalities from dispersal, probabilities were conservatively set at 0.1 for dispersal and 0.4 for building a bomb.

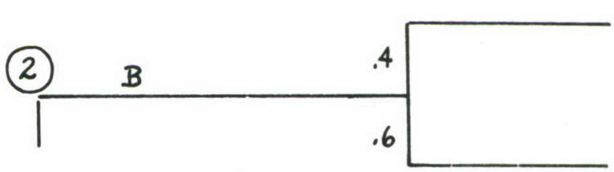
For choice 2, the PuO_2 device was considered less lethal than the Pu device. In addition, the PuO_2 device is much easier to construct and requires less equipment. Therefore, the PuO_2 device was considered much more appealing than the Pu device. However, considering the potential lethalities of a Pu device the probabilities were conservatively assumed to be 0.8 for PuO_2 device and 0.2 for the Pu device.

For choice 4, all options will result in lethalities. Dispersal from a point will produce fewer casualties than dispersal in a line. Dispersal in a building has the potential to produce the fewest casualties, and is isolated to a specific target but the risk involved is much greater. Dispersal from a point was considered most appealing and assumed to be 0.5. Because a specific target can be chosen, dispersal in a building was considered more appealing than dispersal in a line. Therefore, the probabilities are 0.3 for dispersal in a building and 0.2 for dispersal in a line.

Choices 3 and 5 were not weighted and taken to be 0.7 for placement in unpopulated areas and choosing least lethal weather conditions and 0.3 for placement in populated areas and choosing lethal weather conditions.

<u>The Event Tree</u>

This section contains the explanations of the events in the plutonium event tree (Fig 7). Each event consists of a labeling number, letter symbols for the event, and the probabilities for its options. An example is:



The identifying number is 2. The letter symbol indicates that the event is the decision to construct a bomb. The top probability, 0.4, is the

probability that the event occurs, or in this case, the decision is yes. The bottom probability is the probability that the event does not occur or the decision is no.

The following paragraphs are detailed explanations of the events.

1 DV - Diversion of plutonium material

(a) PuO_2 is diverted by theft. The probability of a diversion is 0.635 during 1975 (from Chapter 2).

(b) Plutonium alloy is diverted by theft. The probability of a diversion is 0.635.

2 B - Decision to construct a bomb

(a) The decision to construct a bomb over blackmail or dispersal has a probability of 0.4. Therefore the probability to use either blackmail or dispersal is 0.6.

(b) In this instance the decision to construct a bomb comes after an unsuccessful blackmail attempt. Therefore the two options are the bomb ($p = .4$) and dispersal ($p = .1$). Therefore the decision to build a bomb is 0.8 and use for dispersal is 0.2 for a total probability of one for the event.

3 CV - Convert PuO_2 to Pu Alloy

The ability to convert PuO_2 to Pu alloy is assumed to be one in a time period of 30 days. The desirability of a Pu device is 0.2. In addition, the probability of a successful conversion is influenced by the ability to evade capture.

(a) The probability of evading capture between the diversion and day 30 is 0.290. The total probability is (1) (.2) (.290) = .058.

(b) The probability of evading capture between day 3.5 and 33.5 is 0.348. The total probability is (1) (.2) (.348) = 0.0696.

The probability of not converting PuO_2 to Pu alloy is taken to be the decision to construct a PuO_2 device, or 0.8.

(4) CS - Construct a device

The probability of constructing a device is assumed to be one given 14 days for a PuO_2 device and 60 days for a Pu device. **However,** the probability of not having a pre-detonation is 0.978. In addition, the probability of constructing a device is influenced by the ability to evade capture.

(a) The probability of evading capture between day 31 and day 60 is 0.894. The total probability is (1) (.978)(.894) = 0.874.

(b) The probability of evading capture between the diversion and day 14 is 0.803. The total probability is (1)(.978)(0.803) = 0.785.

(c) Since, in this case, the Pu did not have to be converted, the probability of evading capture between the diversion and day 60 is 0.194. The total probability is (1)(.978)(.194) = 0.190.

(d) The probability of evading capture from day 33.5 to day 93.5 is 0.915. The total probability is (1) (.978)(.915) = 0.895.

(e) The probability of evading capture from day 3.5 to day 17.5 is 0.546. The total probability is (1)(.978)(.546) = 0.534.

Since, at this point, there is no option for this event, the probability for not constructing a device is taken to be zero.

(5) P - Placement in a populated area

The desirability of placing the bomb in a populated area is 0.3. The probability of successfully placing the device is 0.836. The total probability of successfully placing the device in a populated area is (.3) (.836) = 0.251.

The desirability of not placing the device in a populated area, or the placing of the device in an unpopulated area is 0.7. The probability of a successful placement is 0.836. The total probability of successfully placing the bomb in an unpopulated area is (.7)(.836) = 0.585.

Placement in an unpopulated area is considered for a bomb because the dramatic effect is still present without great lethalities.

6 DT - Detonation

The probability of a successful detonation of a homemade bomb is 0.749. Therefore the probability of not having a detonation is 0.251.

7 Y - Achieving a nuclear yield

The ability to achieve a nuclear yield with a homemade device is unknown. Therefore, the assumption is made that a successful nuclear yield will be 20 kilotons and an unsuccessful achievement of yield will be a high explosive detonation. The probability for a successful nuclear yield is assumed to be 0.7 and the probability for an unsuccessful attempt is 0.3. This should offer a conservative estimate of potential lethalities.

8 D - Decision to disperse

The decision for dispersal leads to two options, dispersal and blackmail. The probability of deciding for dispersal is 0.1. The probability of deciding for blackmail is 0.5. Therefore, normalizing so the total equals one yields a probability of 0.167 for dispersal and 0.833 for blackmail, or against no dispersal.

9 PC - Placement in an inert container

The probability of taking the PuO_2 and placing it in an inert container is one in a period of two days. Therefore the success of this event is influenced by the ability to evade capture.

(a) The probability of evading capture between the diversion and day 2 is 0.969. The total probability is (1)(.969) = 0.969.

(b) The probability of evading capture between day 3.5 and day 5.5 is 0.923. The total probability is (1)(.923) = 0.923.

Since the probability of placing the plutonium in an inert container is one, the probability of not placing it in the container is zero.

(10) DI - Dispersal inside a building

(a) The probability of deciding for dispersal inside a building is 0.3. Therefore the probability of deciding against dispersal inside a building is 0.7. The probability of successfully placing the plutonium in a building is assumed to be the same as the probability for successfully placing a bomb, or 0.836. The plutonium is assumed to be distributed throughout the building, possibly through the ventilating system. The total probability for a successful dispersal inside a building is (.3)(.836) = 0.251.

(b) During the process of blackmail, the terrorists are assumed to be in hiding without much movement. Therefore, the more likely point of capture will be in a building. The dispersal of plutonium by explosives will not yield many lethalities, especially if the plutonium is totally confined. Optimal distribution cannot be assumed. In order to present a conservative estimate of lethalities, dispersal inside a building is assumed to be 0.5 and equal to the probability of dispersal outside from a point, where more lethalities are likely.

(11) DP - Dispersal outside from a point

Dispersal from a point is the dispersal of plutonium from one position.

(a) The probability of dispersal outside from a point is 0.5. The option for not dispersing from a point is dispersal from a line with a probability of 0.2. Normalizing so the total equals one yields a probability of 0.714 for dispersal from a point and 0.286 for not dispersing from a point.

Since the dispersal is a simple procedure requiring little time, the assumption is made that it cannot be prevented. In addition, dispersal is assumed to occur in a populated area because it will have a more dramatic effect and dispersal in an unpopulated area will be inconsequential.

(b) Since no other options exist at this point, the probability for dispersal outside from a point is one and for not dispersing outside is zero.

12 DL - Dispersal from a line

Dispersal from a line is the dispersing of the plutonium along a line perpendicular to the wind direction. Since no other options are available at this point in the tree, the probability of dispersal from a line is one.

13 LW - Lethal weather conditions

Lethal weather conditions are those conditions which will yield the greater numbers of lethalities. Because a choice can be made between weather conditions, the probability of choosing a lethal weather condition is 0.3 and 0.7 for a less lethal weather condition. Since the weather conditions are seasonal, the assumption is made that the season is optimal for the decision. The desired weather condition will occur about four days out of a week during its optimal season. Therefore, the time period for outside dispersal is assumed to be two days. Therefore the probability of a successful dispersal is influenced by the ability to evade capture.

(a) The probability of evading capture between day 2 and day 4 is 0.933. The total probability for dispersal in lethal weather is (.3) (.933) = 0.2380. The total probability for dispersal in less lethal weather is (.7) (.933) = 0.653.

(b) The probability of evading capture between day 3.5 and day 5.5 is 0.923. The total probability for dispersal in lethal weather is (.3)

(.923) = <u>0.277</u>. The total probability for dispersal in less lethal weather is (.7) (.923) = <u>0.646</u>.

(c) In this case, the probability of dispersal in lethal weather conditions is the probability of lethal weather occurring. Lethal weather conditions and least lethal weather conditions will cocur four days out of the week during their optimal seasons. Therefore, since both will produce lethalities, conservatism leads to assuming optimal seasons for each. The result is a probability of 4/7 or <u>0.571</u> for dispersal in either weather condition.

14 BL - Decision to blackmail

Since at this point, all other options have been rejected, the probability for deciding to blackmail is <u>one</u>. The probability for deciding not to blackmail is <u>zero</u>.

15 GR - Successful governmental retaliation

The time period for a blackmail attempt was set at one week. Determining the probability of a successful governmental retaliation in this period is difficult because information the government receives when the demands are made can either aid or mislead. Therefore, since either resultant option can lead to lethalities, a convervative attitude is directed toward both options. For a successful retaliation, the government is assumed to complete two weeks of work during the one week period. The probability of a successful retaliation is 0.55, the probability of being captured between the diversion and day 14. For an unsuccessful retaliation, the government is assumed to complete 3.5 days of work during the one week period. The probability of an unsuccessful retaliation is 0.92, the probability of evading capture between the diversion and day 3.5.

16 SD - Self-destruct device

A blackmail attempt with plutonium must be considered similar to a kidnapping because threats involved deal with potential lethalities. Therefore, the plutonium is assumed to be equipped with a self-destruct device. This would be comparable to the ability to kill a kidnap victim if capture is imminent. Since no statistics are available, the probability for the use of the device is assumed to be one and not using the device to be zero. The probability of the device operating is assumed to be 0.749, the probability of a homemade bomb detonating. The total probability for successful self-destruction is (1)(.749) = 0.749.

Consequences

The consequence section compiles the resultant events and probabilities. The consequences are compiled according to the type of event. The lethalities occurring with each type of event are taken from Appendix B if the event is a bomb and from Appendices D and E if the event is dispersal.

Consequence A: Consequence A is a 20 kiloton yield from a Pu device. Consequence A has a total probability of 3.8918×10^{-3}. The result is 25,300 acute lethalities. The lethal probability is 98.46 deaths/year.

Consequence B: Consequence B is a high explosive detonation due to failure to achieve a nuclear yield. Consequence B has a probability of 3.4841×10^{-3}. Lethalities are estimated to be about 40. The lethal probability is .139 deaths/year.

Consequence C: Consequence C is a nuclear yield in an unpopulated area. The probability is 3.614×10^{-2} with possibly 10 lethalities. Since the lethality rate is small, the possibilities of no detonation or no yield was ignored. The lethal probability is .361 deaths/year.

Consequence D: Consequence D is a 0.1 kiloton yield from a PuO_2 device. The probability is 4.239×10^{-3}. The result is 320 acute lethalities. The lethal probability is 1.356 acute deaths/year.

Consequence E: Consequence E is the dispersal of plutonium inside a building. The probability is 5.8×10^{-3}. The dispersal is assumed to be uniform throughout the building. Approximately 0.2 mg/m^2 is required to produce 100% cancer lethalities and 2 mg/m^2 to produce 100% acute lethalities. In a ten story building with 93,000m^2 of floor space, only 20 gms is needed for 100% cancer lethalities and 200gms for 100% acute lethalities. Therefore, since the diversion results in the acquisition of 40kgm of material the potential for lethalities is very great. If the building is assumed to hold 3,000 people, the acute probability is 17 deaths/year. However, the potential to disperse inside other buildings exists, but each building must be considered a new attempt. Therefore, the probability of success for each successive attempt lessens.

Consequence F: Consequence F is the outside dispersal of plutonium from a point during lethal weather conditions. The probability is 7.761×10^{-2}. As a result, there will be 16,714 cancer lethalities (45.2% of the exposed population) and 142 acute lethalities (.4% of the exposed population). Approximately 35 mi^2 of metropolitan area will be covered. The cancer probability is 1,297 cancer victims/year. The acute lethal probability is 11 deaths/year. The total victim probability (for both acute and future cancer lethalities) is 1,308 victims/year.

Consequence G: Consequence G is the outside dispersal of plutonium from a point during less lethal weather conditions. The probability is 8.2051×10^{-2}. There will be no acute lethalities and 520 cancer lethalities (.16% of the exposed population). Approximately 350 mi^2 will be exposed. The acute lethality probability is zero. The cancer probability is 42.7 cancer victims/year.

Consequence H: Consequence H is the outside dispersal of plutonium from a line during lethal weather conditions. The probability is 1.35×10^{-3}. There will be 34.642 cancer lethalities (94% of the exposed population) and 2,211 acute lethalities (6% of the exposed population). This is a 100% kill probability. The area exposed is 37 mi^2. The cancer probability is 46.8 cancer victims/year. The acute lethal probability is 3 deaths/year.

Consequence I: Consequence I is the outside dispersal of plutonium from a line during less lethal weather conditions. The probability is 3.176×10^{-3}. There will be no acute lethalities and 31,486 cancer lethalities (9.6% of the exposed population). The area exposed is 328 mi^2. The acute lethal probability is zero. The cancer probability is 100 cancer victims/year.

Consequence J: Consequence J is the dispersal of plutonium in a building by self-destruction during an unsuccessful blackmail attempt. The assumption has been made that the explosion is fairly well confined and a minimum of Pu will escape. As a result, the only lethalities will be people in the proximity of the explosion. Therefore the lethal probability is assumed to be less than 0.1 deaths/year.

Consequence X: Consequence X is the result of the failure of a device to detonate. The possibility of the terrorists recovering the device and re-entering the event tree does exist. However, the probability to do so was assumed to be zero to prevent endless loops within the event tree.

Evaluation

The successful detonation of a Pu device (A) is the most dangerous threat in terms of acute lethal probability with 98.46 deaths/year. This is followed by dispersal inside a building (E) with 17 deaths/year. Although Consequence A appears to be five times larger, this is not

necessarily the case. The 17 deaths/year is based on dispersal in only one building. Since one building requires only 200 gm of material then it is not necessary to divert 40 kg, so the relative probability is higher than for those events which must have 40 kg nominal. The method of deriving the probability of the initiating event does not permit an adjustment for the amount diverted. It must be pointed out that the lethalities from several successful dispersals in separate buildings can approach the range of device lethalities.

Of lesser importance in considering acute lethality probabilities are outside dispersals during lethal weather conditions (11 and 3 deaths/year) and the successful detonation of a PuO_2 device (1.356 deaths/year). All other consequences result in less than one death/year and may be neglected since they are at least one order of magnitude below the mentioned consequences.

However, if cancer probabilities are considered, then the dispersal consequences become dominant based on supplied information. No cancer lethalities were supplied for bomb consequences.

Dispersal outside from a point during lethal weather conditions dominates with 1,297 cancer victims/year. The next event is dispersal outside from a line during less lethal weather conditions with 100 cancer victims/year. In addition, the two remaining outside dispersal consequences result in 47.7 and 46.8 cancer victims/year.

The sum of the lethal probabilities is a probability of 131.42 acute deaths/year from a diversion of plutonium. The sum of the cancer probabilities is 1491.5 cancer victims/year as a result of a plutonium diversion. Division by the population of the United States ($2x10^8$) gives the probability per person per year. Therefore the acute lethal probability

per person is 6.57×10^{-7} acute lethalities person/year and the cancer probability per person is 7.46×10^{-6} cancer victims-person/year. Table VIII contains a breakdown of these probabilities by consequence.

Consequence	Acute Lethalities $\frac{\text{Person}}{\text{Year}}$	Cancer Victims $\frac{\text{Person}}{\text{Year}}$
Pu Bomb (A)	2.40×10^{-6}	----
H. E. Yield (B)	3.39×10^{-9}	----
Pu or PuO_2 in unpop. area (C)	8.80×10^{-9}	----
PuO_2 Bomb (D)	3.31×10^{-8}	----
Dispersal inside one building (E)	4.15×10^{-7}	----
Dispersal outside from a point, lethal weather (F)	2.75×10^{-7}	3.27×10^{-5}
Dispersal outside from a point, less lethal weather (G)	0	1.08×10^{-6}
Dispersal outside from a line, lethal weather (H)	7.5×10^{-8}	1.20×10^{-6}
Dispersal outside from a line, least lethal weather (I)	0	2.5×10^{-6}

Table VIII. Summary of Plutonium Diversion Consequences.

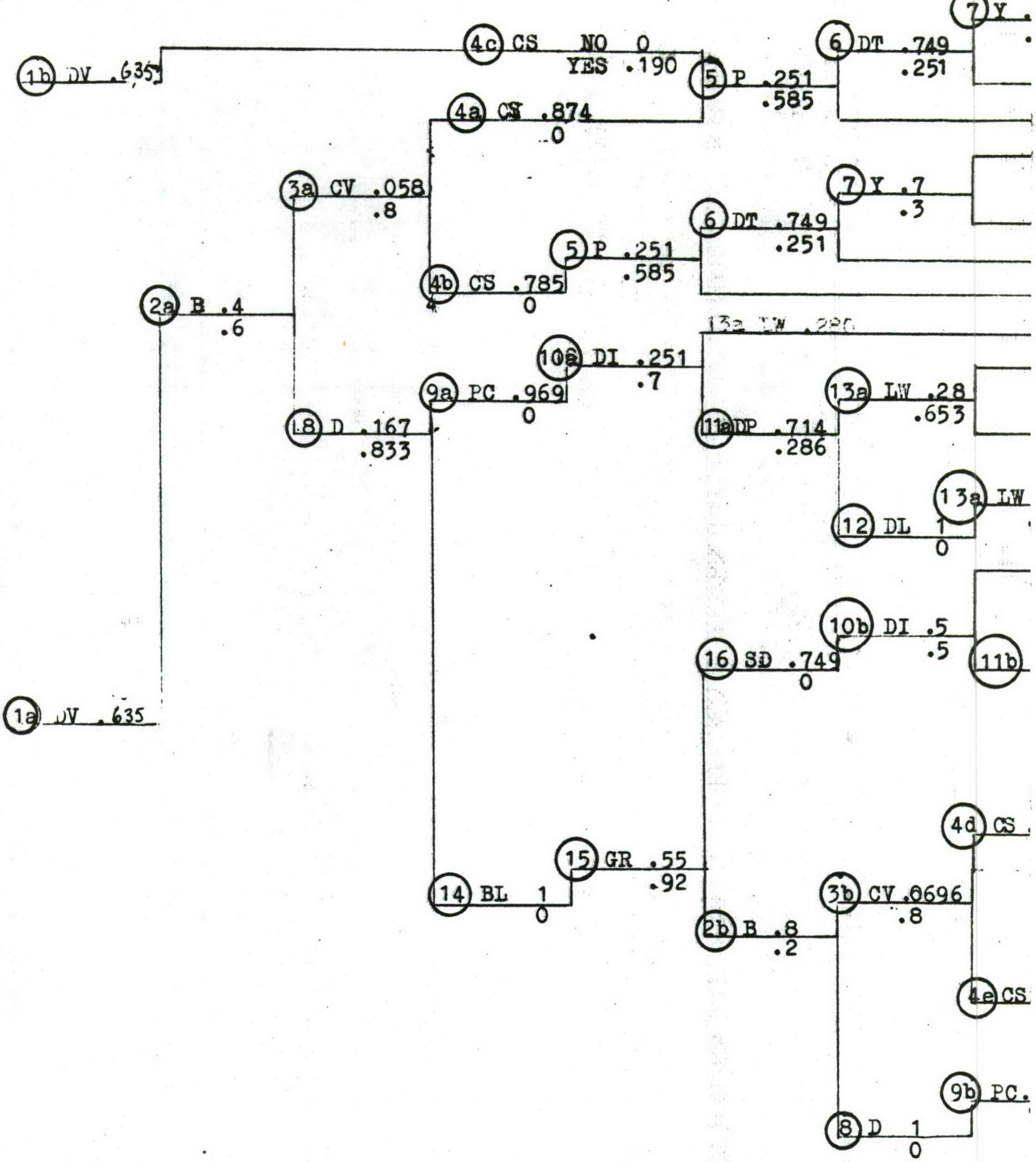


Fig. 7 The Plutonium Event Tree

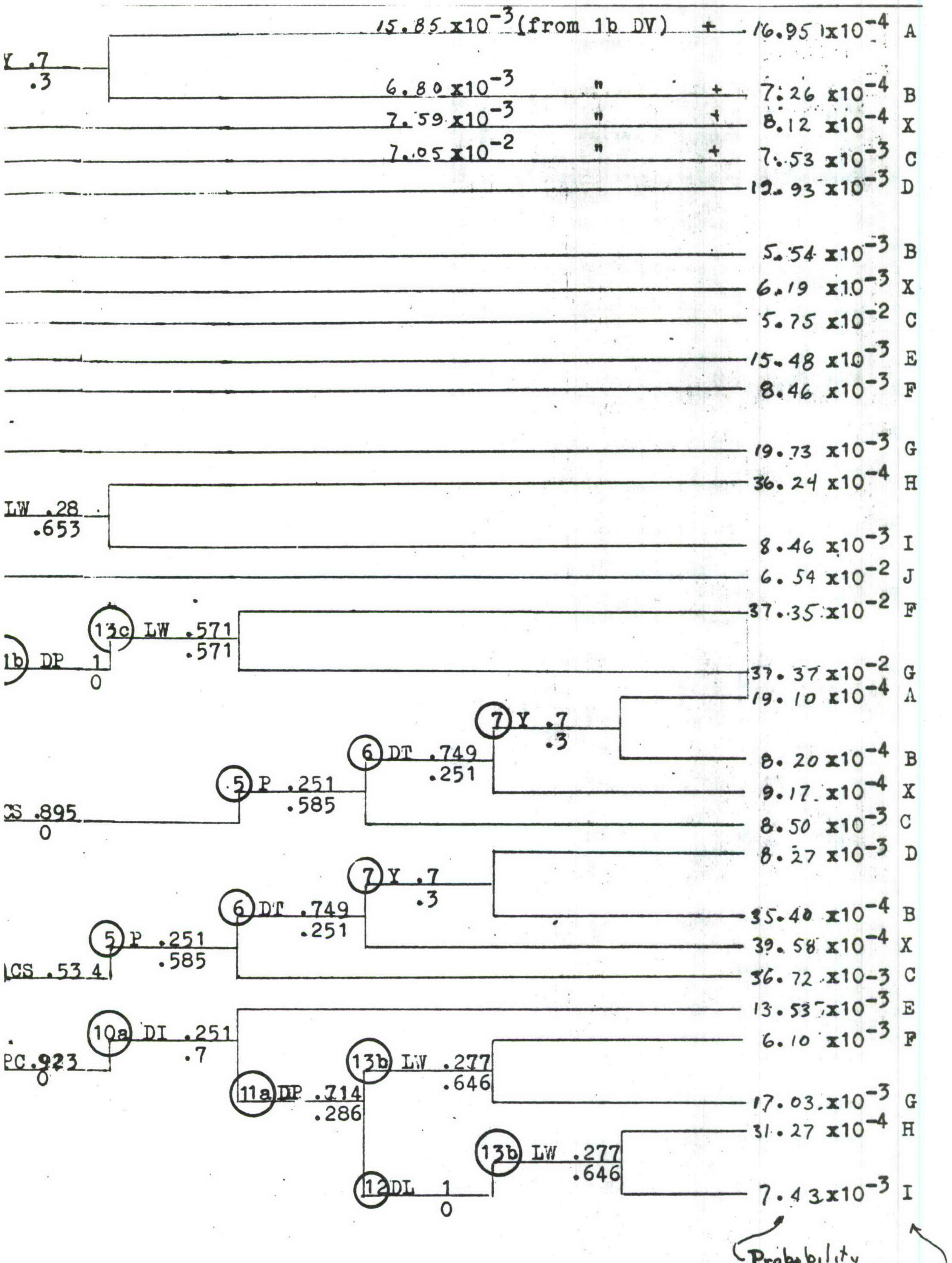


Fig. 7 Con't: The Plutonium Event Tree

VI. COMPARISON OF RISKS & DISCUSSION

Now that risks have been determined in terms of lethalities per person-year from the various event trees, the relative risks can be assessed by comparing the results of the three trees. Events are ordered from highest to lowest risk so that individual events and risks can be seen in proper perspective. Table X contains the ordered listing of the risks. Additionally, the risks can be compared to the risks associated with other events such as those shown in Table XI. This ordering also provides a method for identifying those areas which require improved security measures.

The highest risk as determined from the event trees involves the large yield weapon, and the risk decreases as the yield decreases. Whenever there were two different modes of detonating the device, the proper detonation of a weapon always gave the greatest risk. With the exception of the large yield operational weapon, all of the lethalities were less than 3.5×10^{-6} lethalities per person-year.

The risk from a homemade plutonium device is approximately an order of magnitude lower than a homemade U^{235} device. The difference is to be expected since Pu^{239}, which is both pyrophoric and radiologically quite toxic, must be worked in an artificial environment. U^{235} is of course, a stable metal that requires little precaution when being manufactured.

The rest of the calculated lethalities for nuclear explosive devices fall in a reasonable order. While a 5 kiloton U^{235} device will kill the same number of people regardless of its mode of manufacture, it is more difficult to produce a homemade bomb from UF_6 than from uranium metal. One then expects a lower risk from a theft of UF_6 than

Type Device	Yield (Kt)	Lethalities ** / Person - Yr.
Weapon (weapon fusing system)	large yield*	5.9×10^{-5}
Weapon (fabricated fusing system)	large yield*	4.9×10^{-5}
Weapon (weapon fusing system)	small yield*	3.4×10^{-6}
Weapon (fabricated fusing system)	small yield*	2.8×10^{-6}
Gun Type (diverted U^{235} metal)	5	2.1×10^{-6}
Gun Type (diverted UF_6)	5	1.8×10^{-6}
Gun Type (diverted U^{235} metal)	1	8.0×10^{-7}
Gun Type (diverted UF_6)	1	7.2×10^{-7}
Gun Type (diverted Pu)	20	4.9×10^{-7}
Gun Type (diverted Pu)	.1	6.9×10^{-9}
Gun Type (diverted Pu, HE only)		7.0×10^{-10}
PuO_2 Dispersal outside		
(Favorable weather conditions)		1.5×10^{-8}
PuO_2 Dispersal inside		8.5×10^{-8}

TABLE X. SUMMARY OF INDIVIDUAL RISK FROM A DIVERSION OF SPECIAL NUCLEAR MATERIALS.

* See Chapter V for actual yield values.

** Based on U. S. population of 2.13×10^{8} people.

TABLE XI

INDIVIDUAL RISK OF ACUTE FATALITY BY VARIOUS CAUSES

(FROM WASH-1400 REF. 57)

Accident Type	Total Number for 1969	Approximate Individual Risk Acute Fatality Probability/yr[1]
Motor Vehicle	55,791	3×10^{-4}
Falls	17,827	9×10^{-5}
Fires and Hot Substance	7,451	4×10^{-5}
Drowning	6,181	3×10^{-5}
Poison	4,516	2×10^{-5}
Firearms	2,309	1×10^{-5}
Machinery (1968)	2,054	1×10^{-5}
Water Transport	1,743	9×10^{-6}
Air Travel	1,778	9×10^{-6}
Falling Objects	1,271	6×10^{-6}
Electrocution	1,148	6×10^{-6}
Railway	884	4×10^{-6}
Lightning	160	5×10^{-7}
Tornadoes	91[2]	4×10^{-7}
Hurricanes	93[3]	4×10^{-7}
All Others	8,695	4×10^{-5}
All Accidents		6×10^{-4}
Nuclear Accidents (100 reactors)	0	3×10^{-9}*

[1] Based on total U. S. population, except as noted.

[2] (1953-1971 avg.)

[3] (1901-1972 avg.)

*Based on approximately 15 million people located within 20 miles of nuclear power plants. If the entire U. S. population of about 200 million people were to be used, then the value would be 2×10^{-10}.